CONTRACTOR REPORT

Public Interest Energy Research
CALIFORNIA ENERGY COMMISSION

Environmentally-Preferred Advanced Generation

Durability of Catalytic Combustion Systems

APPENDIX VII: Xonon Production Readiness

Gray Davis, *Governor*

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CALIFORNIA ENERGY COMMISSION

RESOURCES AGENCY

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is a task topical report for the **Durability of Catalytic Combustion Systems Project,** conducted by **Catalytica Energy Systems, Inc**. The report is entitled **"Xonon Production Readiness".** The overall project contributes to the **Environmentally-Preferred Advanced Generation** program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

I. Introduction

In managing the PIER Program, the California Energy Commission (the Commission) has a goal of bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. In pursuit of this goal, the Commission requires that Contractors who receive PIER funding deliver a Production Readiness Plan that describes the proposed manufacturing processes, capabilities, constraints, and timing to achieve a commercially viable product. The degree of detail in the Plan should be directly related to the complexity of producing the proposed product and its state of development. That is, the more complex the process and the closer it is to being market-ready, the more important it is that the Commission has the information to assess its viability for bringing products to the marketplace.

The product manufactured by Catalytica Energy Systems, Inc. (CESI) to achieve ultra-low emissions from gas turbines is the Xonon® catalyst module. For the Xonon module:

1. The production process is relatively simple.
2. Development and optimization of the process have been ongoing for ten years.
3. The equipment configuration and critical steps in the commercial production process were proven more than five years ago.
4. The first commercial Xonon catalyst modules were produced for shipment in August 2001 --- the process works. Modules are manufactured in response to sales of the associated Xonon-equipped turbines. As of January 2002, Xonon catalyst modules have been produced for three commercial Kawasaki M1A-13X gas turbines.

Several turbine components besides the catalyst module must be specially designed to assure the effectiveness of the Xonon combustion system. While CESI typically works in partnership with each turbine manufacturer to design such key components as the preburner, the fuel-air mixer, the air staging system, and the necessary controls system, the manufacturer is responsible for the final design, manufacturing, and performance of those components.

None of the CEC PIER Program funds have been directed at developing or refining the module manufacturing process.

II. Overview

A Xonon catalyst module consists of the catalyst itself and the surrounding container. An example is shown schematically in Figure 1. The catalyst stage is typically a cylindrical shape with a diameter of from 8 inches to more than 20 inches and a thickness (height) of 2 inches to 5 inches. The unit in Figure 1 is a single stage module; but, depending upon the application, the optimal system design can consist of 1, 2 or 3 catalyst stages stacked within a single container. The container must be designed: 1) to maintain the physical position of the catalyst against the aerodynamic forces of the combustor gas flow, and

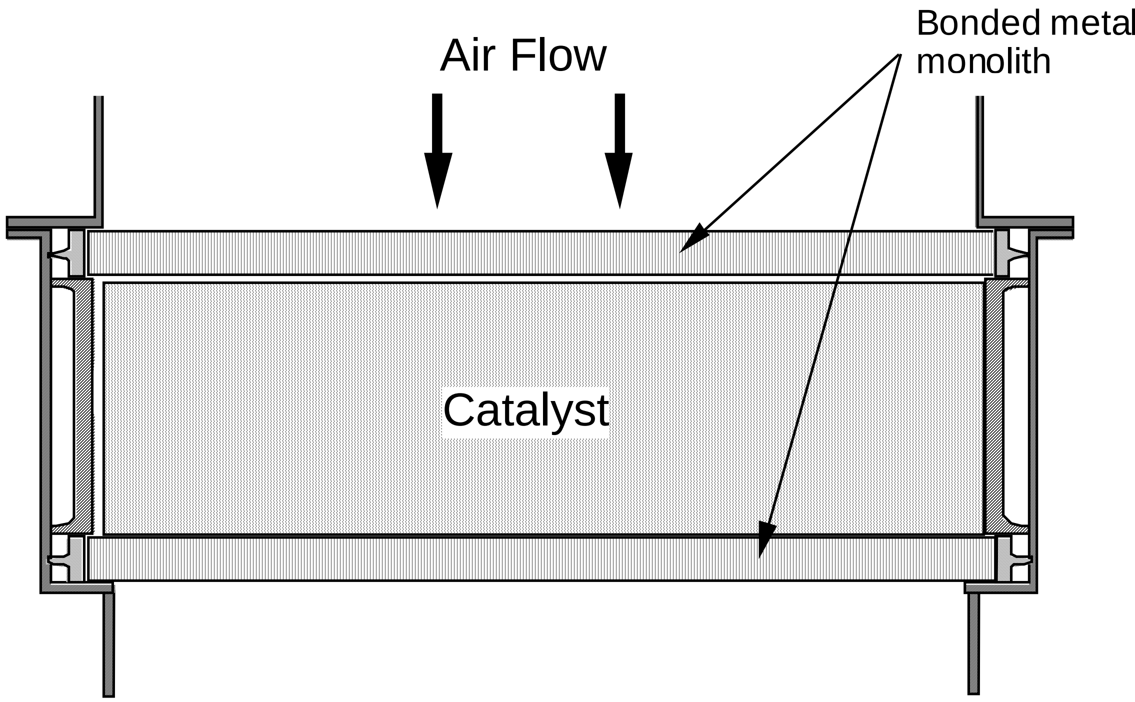

Figure 1 Schematic diagram of the catalyst module with bonded metal monolith (BMM) structures at inlet and outlet

2) to seal the catalyst perimeter against gas leakage during the thermal and flow transients of turbine operation. [Note: Design aspects of the Bonded Metal Monolith (BMM) supports for the catalyst stages in the module are the subject of a separate topical report for this PIER 1 project (cf. *Combustion Catalyst Axial Support Mechanical Durability*, by John Barnes and Marco Velasco, 15 September 2001).]

CESI has a manufacturing operation in Mountain View, CA that produces the catalyst modules for the commercial Kawasaki 1.4-megawatt M1A-13X gas turbines. The catalyst material is manufactured in-house solely by CESI. The mechanical parts of the container are designed by CESI, fabricated by outside vendors, and assembled at the CESI facility. The manufacturing process for the catalyst itself has been under development and refinement for nearly ten years. The currently proven and available production capacity of 40 Kawasaki M1A-13X modules per year will be adequate to support the expected initial commercial demand for six Xonon-equipped Kawasaki turbines. A photograph of the Mountain View manufacturing facility is reproduced in Figure 2.

CESI has attained ISO 9001 registration for its catalyst manufacturing operation and the associated quality assurance procedures. While the projected initial commercial demand for Xonon modules can be met using the Mountain View manufacturing facility, planning is underway to install additional annual production capacity of 100 Kawasaki M1A-13X modules at a more spacious site in the Phoenix, AZ area. The new site will be located in

Hewson Development Corporation's Fiesta Tech Centre in Gilbert, Arizona at 1388 N.
Figure 2 Catalytica Energy Systems, Inc. manufacturing facility in Mountain View

Tech Boulevard. The 43,472 square-foot build-to-suit facility will house various administrative functions as well as the Company's Engineering Center and its commercial manufacturing operations. CESI will begin to occupy this new facility in October 2001, with a dedicated commercial module production operation scheduled to come on-line next year.

Production of a Xonon catalyst module involves the following steps: (1) raw material receiving and inspection, (2) foil preparation, (3) catalyst preparation, (4) catalyst installation in the container, and (5) catalyst module testing. The catalytic components are produced entirely on site using proprietary processes and equipment developed at CESI. The raw materials for these components are sourced from US-based suppliers except when a US-based source of supply cannot be identified. Over 90% of the raw materials used for these components are sourced from within the US. CESI has already demonstrated success in implementing statistical process control tools and Failure Modes and Effects Analysis (FMEA) to identify and correct production challenges.

III. Production Capacity Constraints

There are no significant capacity constraints in CESI’s current production systems. Moreover, the modular design of the CESI catalyst manufacturing operation allows for facile expansion of capacity when the need arises up to a level of 100 Kawasaki M1A-13X modules per year. Larger equipment and the associated issues of equipment scale-up are not required to achieve an increase in Xonon catalyst production volume. Production capacity is a matter only of throughput rate, not of equipment size *per se*. Thus, capacity can be added simply by installing a replicate of the grouping (“cell”) of already proven machines. This is reflected in the floor plan shown in Figure 3 for the new CESI manufacturing operation in Gilbert, AZ. In the diagram, CELL 1 will provide the initial supplement to the current production capability in Mountain View, CA (Figure 2). The CELL 1 equipment will match the design of the proven machines now in place in

Figure 3 Floor plan of Catalytica Energy Systems, Inc. manufacturing facility in Gilbert, AZ

Mountain View. When the business requires further expansion of production, CELL 2 and then CELL 3 can be installed and brought on line at the Gilbert site. Process development activities will continue to be carried out in Mountain View.

IV. Identification of Hazardous or Non-recyclable Materials.

There are currently no hazardous or non-recyclable materials in CESI's Xonon catalytic combustion systems.

V. Projected Product Cost

Many factors, some within and some outside of CESI's control, will affect the cost of the Xonon module and the associated combustion system. Certain of the factors are typical of any manufacturing process:

- Module size
- Raw materials costs
- Unit production volume
- Selling, general, and administrative costs incurred by CESI

For the Xonon system, the interplay between the module design (and, thus, cost) and the requirements of each individual gas turbine adds an extra dimension of complexity to the estimation of product cost for a given application. Specifically,

- Different combustor configurations (e.g., single combustor, multi-combustor, or annular) can be used to generate the same turbine power output. The design and cost of the catalyst module(s) for the turbine's combustion system will depend heavily upon the configuration chosen.
- Even for a given combustor configuration, each turbine model requires a unique Xonon module design. Besides the turbine size (commonly expressed as the maximum electrical power output), the individual sets of temperatures, pressures, and air flow rates that define each turbine's operating cycle are critical parameters for designing the catalyst module(s).
- The product that is marketed to the end user is the complete gas turbine, not simply the Xonon module produced by CESI. Thus the turbine manufacturer, not CESI, dominates the cost and pricing features of installing Xonon technology.

In spite of the complexities and uncertainties, CESI recognizes the Commission's desire to have a basis for estimating the commercial implications of applying Xonon technology to the gas turbine market. With the caveats listed above, then, CESI has projected a production "should cost" for three turbine size classes, based upon each Xonon module being in full-scale production. The cost of the Xonon modules is expressed as a range due to the reasons outlined above; so the values are rough order of magnitude figures and should be used for informational purposes only.

Small Turbines (1 - 15 MW) = $10,000-$13,000/MW on an average basis.
Medium Turbines (15 - 60 MW) = $7,000-$9,000/MW on an average basis.
Large Turbines (60 -170 MW) = $4,000-$6,000/MW on an average basis

VI. Commercialization Investment

CESI plans to spend $10M to launch the commercial product, which includes $6M for new equipment and $4M for establishing the manufacturing facilities.

VII. Production Implementation Plan

CESI plans to begin high-volume production in 1Q 2003, using one manufacturing cell with a capacity of 100 Kawasaki M1A-13X modules per year. In order to meet this date, CESI is currently focusing its efforts in the following areas:

(1) Upgrade of existing manufacturing equipment in Mountain View
(2) Development and testing of next-generation catalysts in Mountain View
(3) Development of new high-volume production equipment for Gilbert, AZ
(4) Competitive quoting and developing multiple ISO certified sources for all parts

CESI currently has enough capacity in Mountain View to meet expected demands for at least the next year and has designed the facility (see Figure 3) in a modular manner to facilitate further expansion quickly. Development of the new Gilbert facility will enable CESI to meet all sales forecasts for the foreseeable future.